IR and Beam-beam

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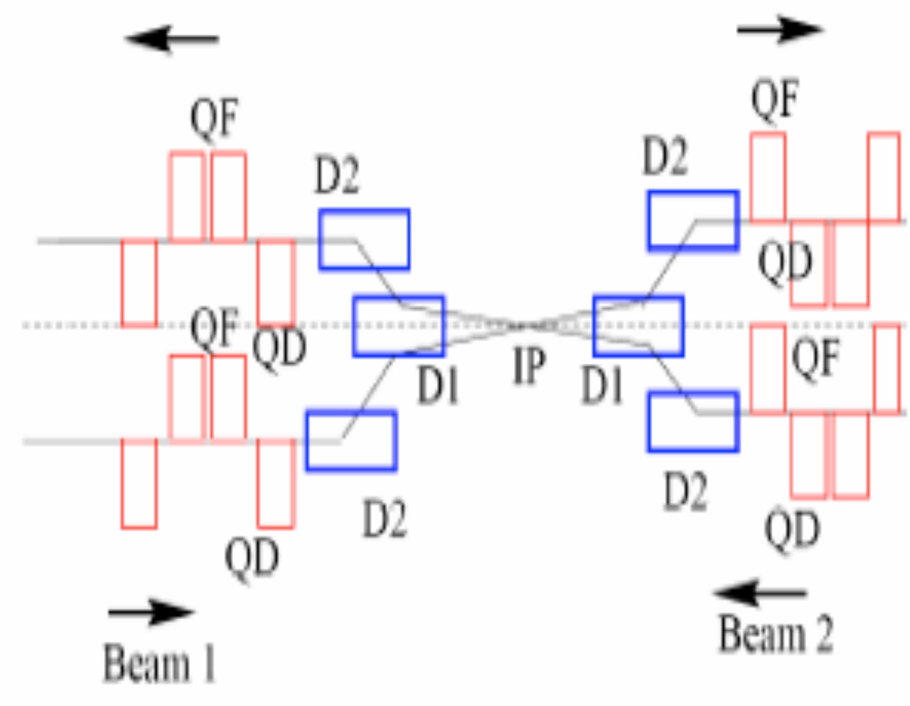
- ***Quads first, 2 dipole 1st options***
- ***L*: Luminosity, chromaticity***
- ***Beam-beam effects***
- ***Energy Deposition***
- ***Conclusions from Valencia***
- ***Next steps***

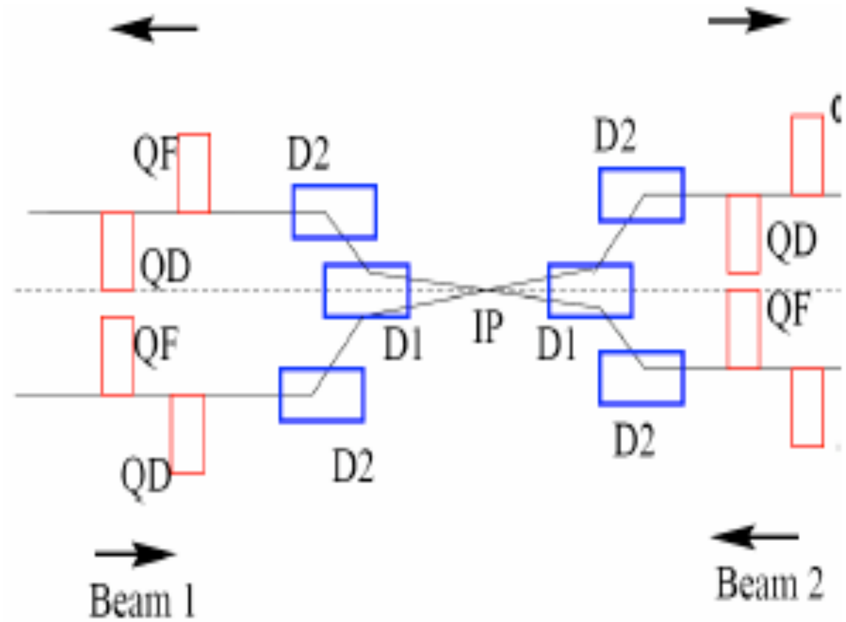
IR Design Issues

- Requirements on magnet fields and apertures
- Optically matched designs at all stages
- Closest approach of magnets to the IP (L*)
- Beam-beam interactions
- Chromaticity (linear & non-linear) correction
- Non-linear correctors for field errors of IR magnets
- Energy deposition
- Dispersion correction
- Susceptibility to noise, ground motion; emittance growth
- Impact of Nb3Sn magnets, e.g flux jumps

….. All need to be considered in defining the luminosity reach

Dipole First: Two Flavours

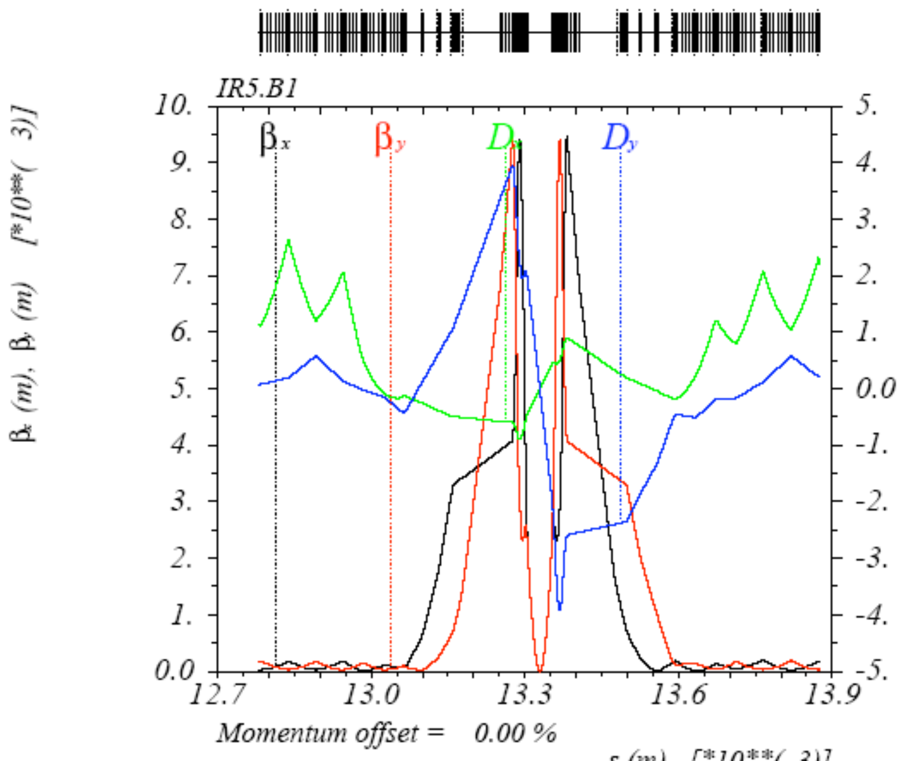




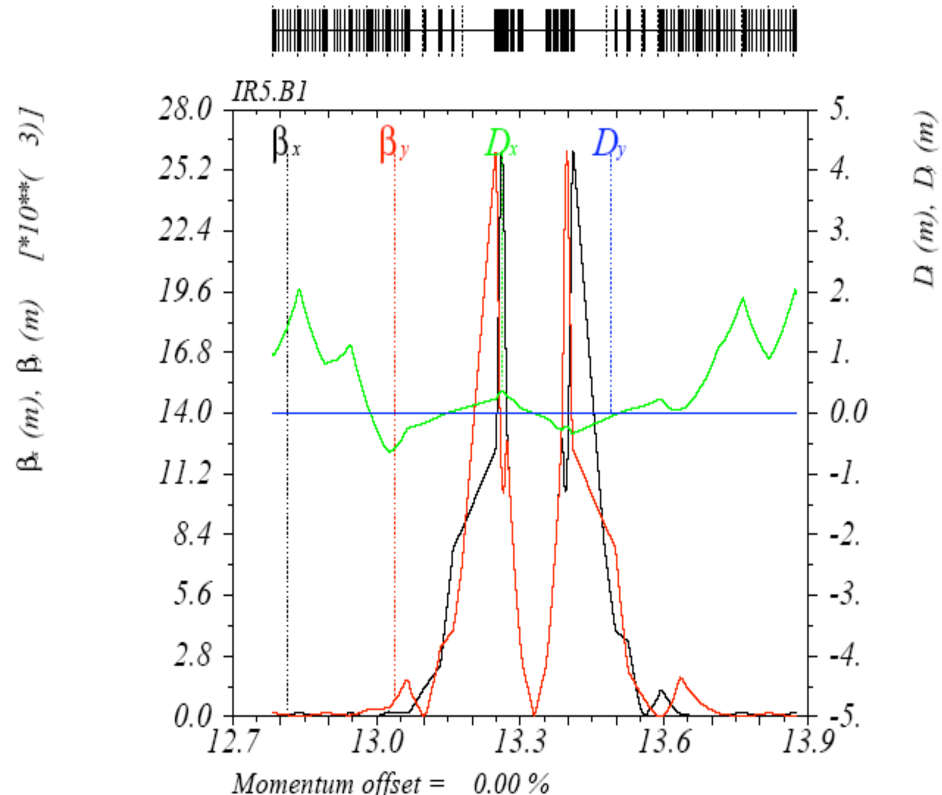
Triplet Focusing
Anti-symmetric about IP

Doublet Focusing
Symmetric about IP

Insertions at collision optics



Quads First



Dipoles First: Triplets

Both optics: $\beta^* = 0.25$m

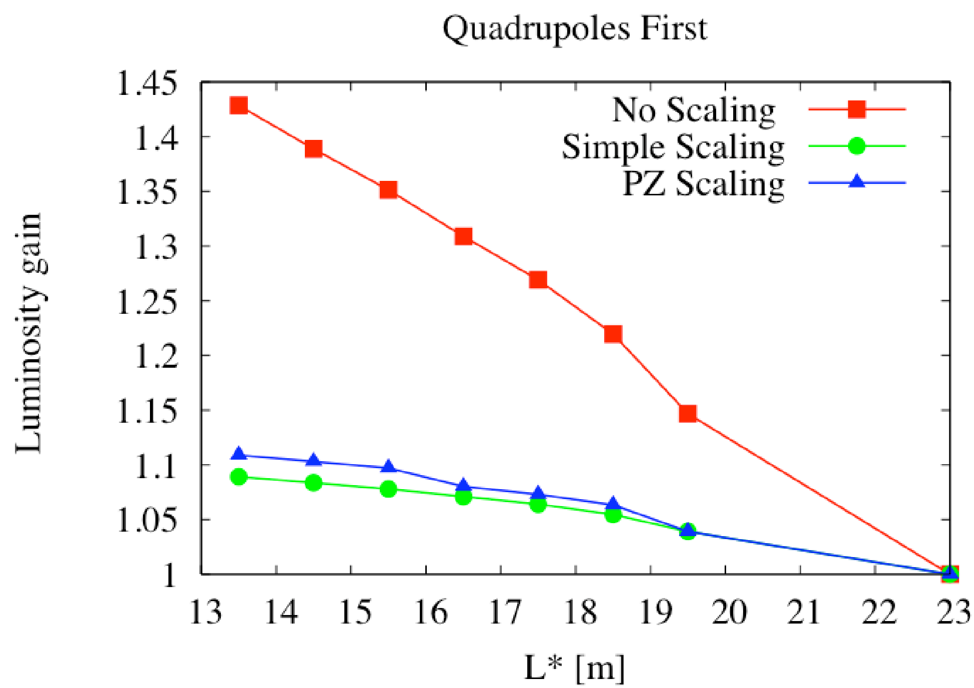
Dipoles 1st: Maximum beta function ~ 3 times larger than in the quads first optics

Luminosity vs Lstar (quadrupoles first)

Matching conditions

- From Q4 left to Q4 right
- β^{max} kept the same
- Quad lengths changed, gradient constant.

L* [m]	β* [m]
23	0.25
19.5	0.22
18.5	0.205
17.5	0.197
16.5	0.191
15.5	0.185
14.5	0.180
13.5	0.175



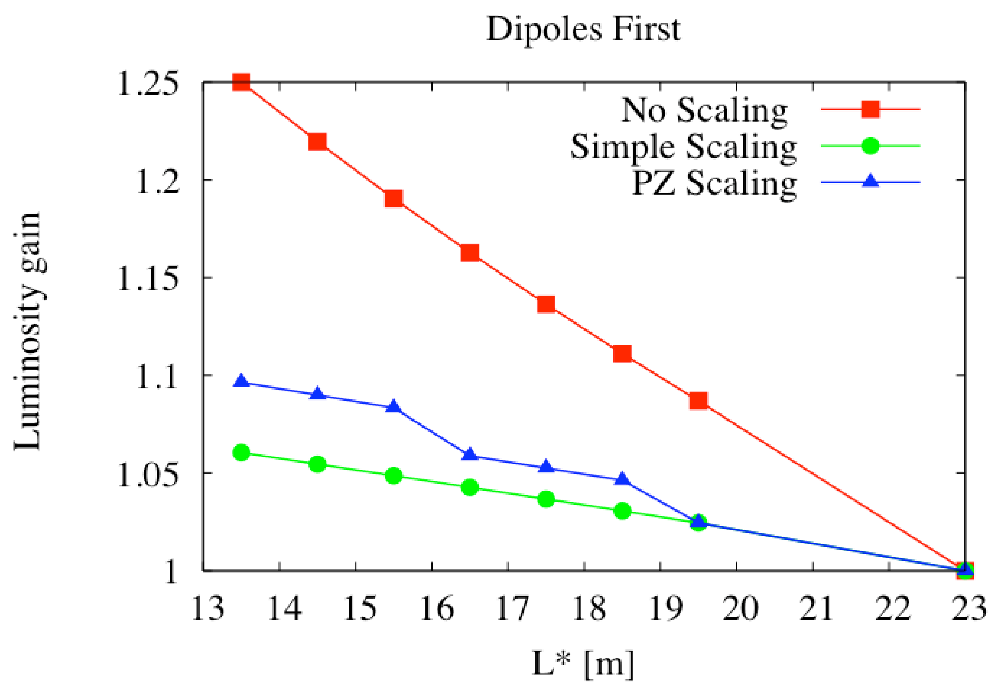
PZ: Y. Papaphilippou & F. Zimmermann

At constant N_b, reducing L* is worthwhile only if the crossing angle does not have to scale as $1/\sqrt{\beta^*}$. Else, weaker bb effects may allow increase in intensity as L* is reduced.

Luminosity vs Lstar (dipoles first)

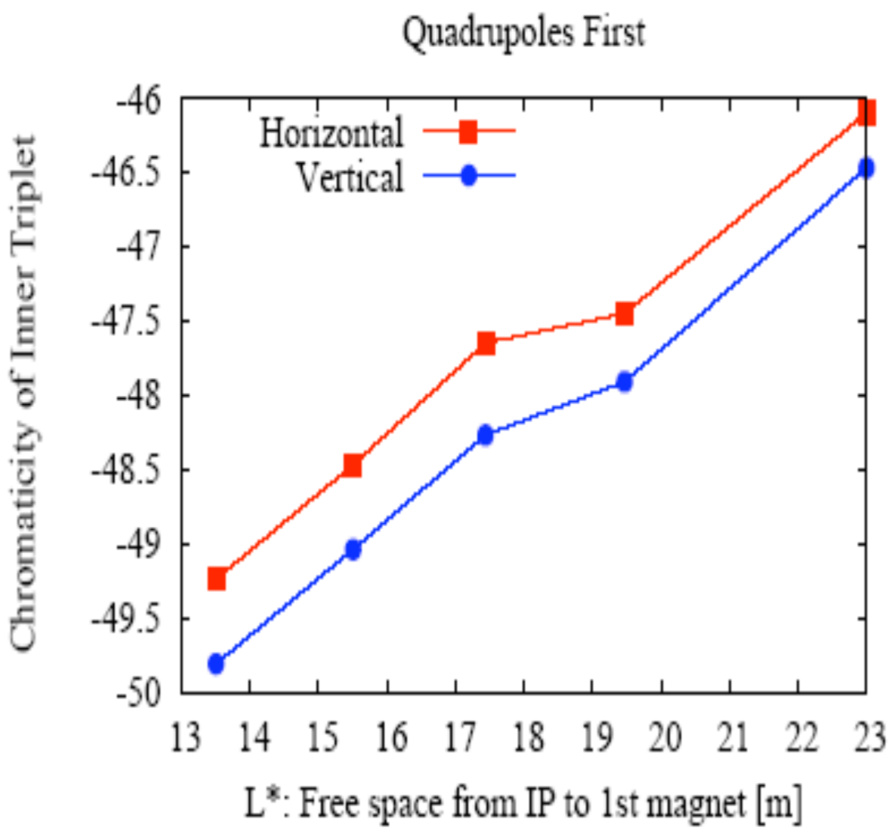
LARP

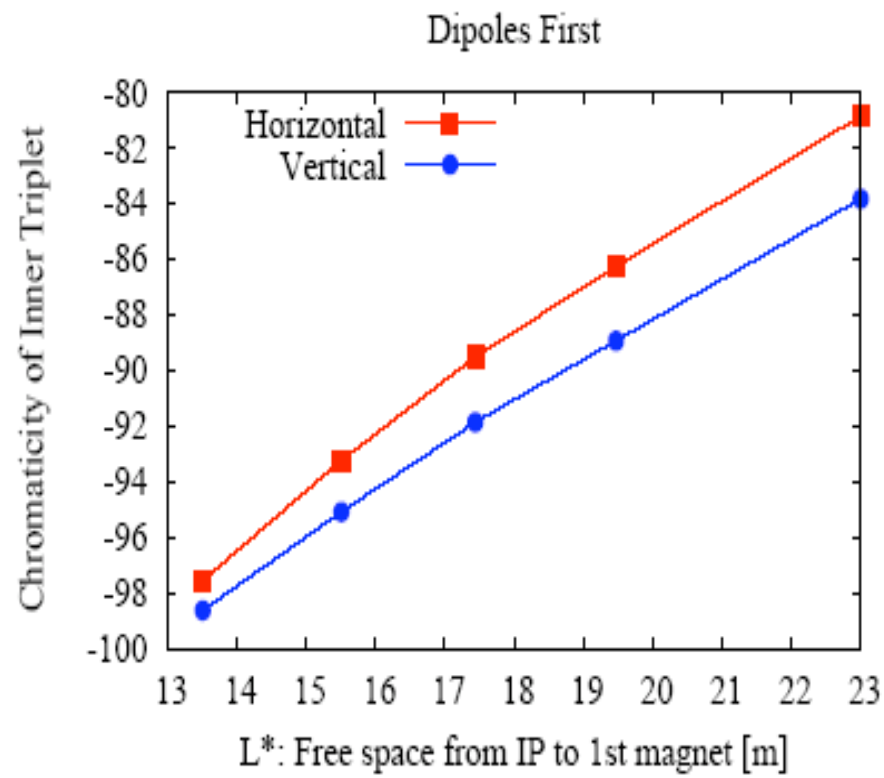
Lstar [m]	β* [m]
23	0.25
19.5	0.23
18.5	0.225
17.5	0.22
16.5	0.215
15.5	0.21
14.5	0.205
13.5	0.20



- Matching from Q4 to Q4 - similar conditions as with quads first
- At larger L*, number of parasitics about the same, crossing angle must scale as 1/√ β* , gain in luminosity limited
- At smaller L*, number of parasitics decrease, crossing angle need not scale as 1/√ β*, as PZ, slightly larger gain in luminosity

Chromaticity vs Lstar





- Quads 1st: Q' increases by ~10% as L* is reduced from 23m to 13m
- Dipoles 1st: Q' increases by > 20% as L* decreases from 23m to 13m. About 35 units per plane from the 2 IRs.

Inner Triplet Parameters

Larger triplet aperture

- larger βmax hence lower β^* (luminosity)
- larger crossing angle (beam-beam)
- larger collimator gap (impedance)

Limit on aperture is set by magnetic stresses, upper limit of what is achievable ~ 110 - 120 mm

If pole tip field stays constant, larger aperture is preferable to larger gradient.

Smaller L*

Allows smaller β^* but gain in luminosity is small if crossing angle is larger

Better to use it for smaller β-max: lower chromaticity and relaxes field quality requirements.

Non-linear chromaticity correction

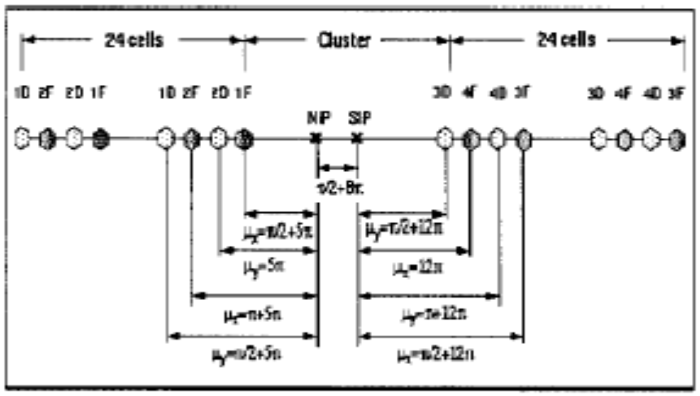


Figure 1. Local Sextupole Distribution

After global linear correction

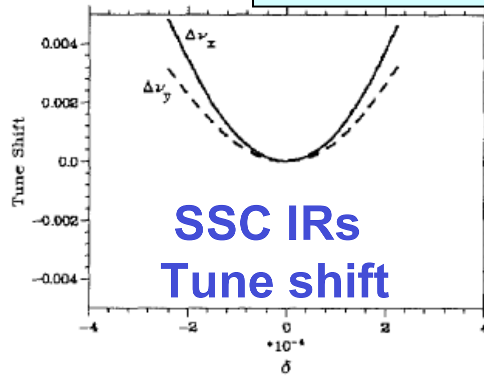


Figure 3. Tune variation with δ : Global correction

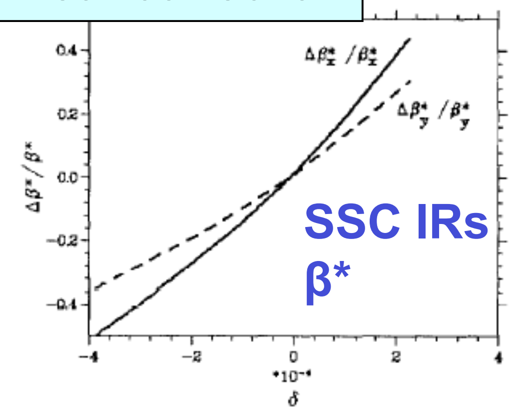


Figure 4. Variation of β* with δ : Global correction

Scheme developed for SSC

- **Used 6λ cells on a side of each IR**
- **Did not rely on cancellation of 2 IRs**

T. Sen, Y. Nosochkov, F. Pilat, R. Stiening, D. Ritson, PAC 1993

Application to quads 1st - initial results are promising with sextupoles at 1500 T/m^2

After local nonlinear correction

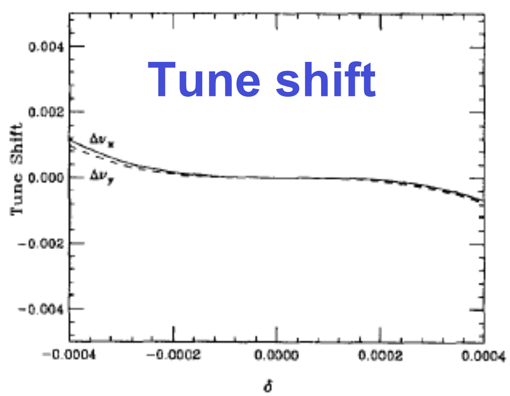


Figure 5. Tune variation with δ : Local correction

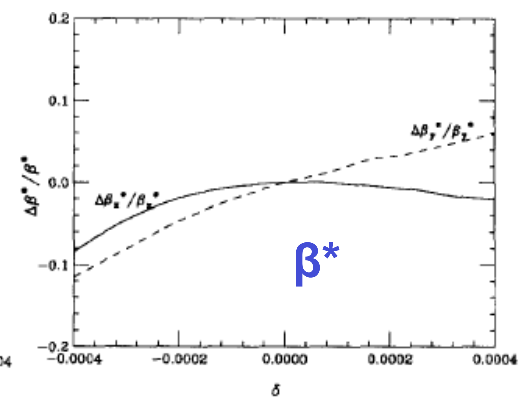


Figure 6. Variation of β* with δ : Local correction

Beam-beam analysis

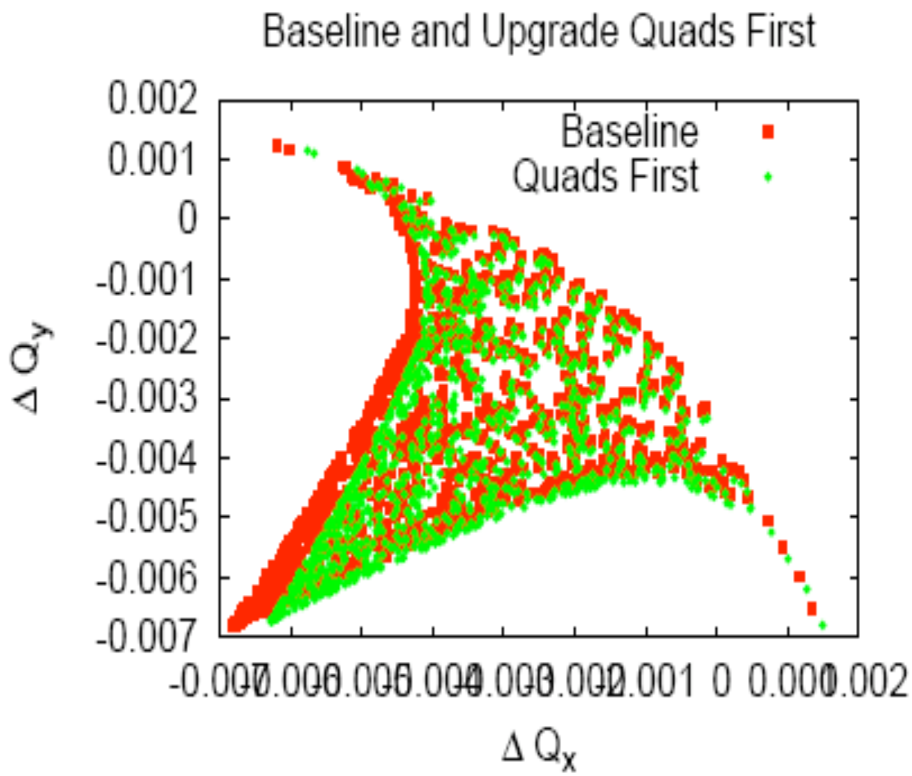
Beam-beam calculations to compare baseline and upgrade optics

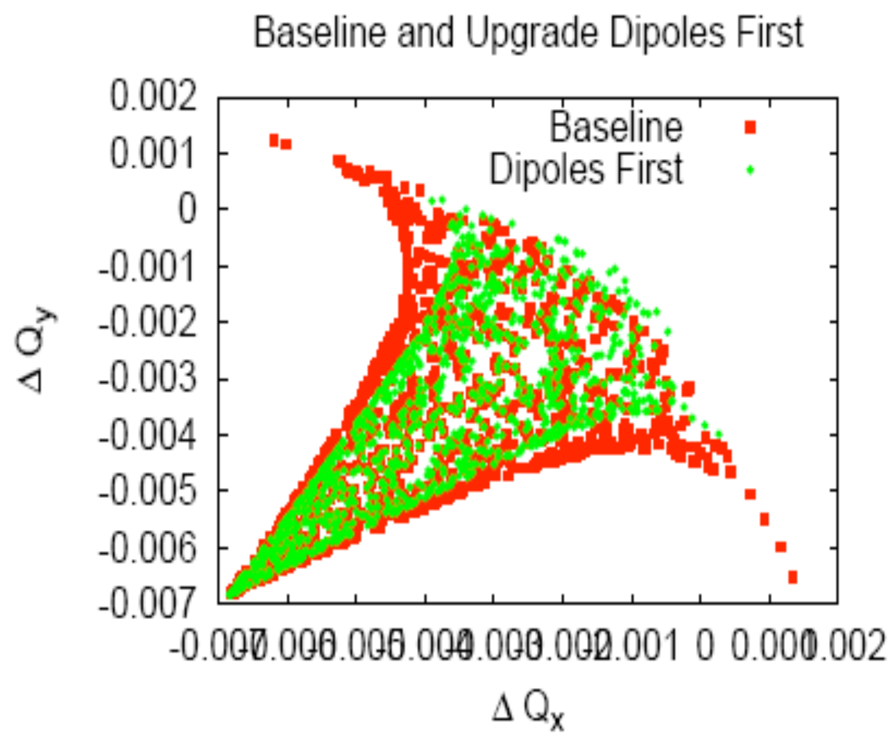
- Tune footprints
- Resonance driving terms - analytical derivation in Sen et al, PRSTAB (2004)
- Simulations with BBSIM
  - amplitude and emittance growth
  - diffusion coefficients
  - lifetimes from solution of the diffusion equation (in progress)

No other non-linearity (either chromaticity sextupoles or IR field errors) at present included in the model. IR errors to be included later.

LARP

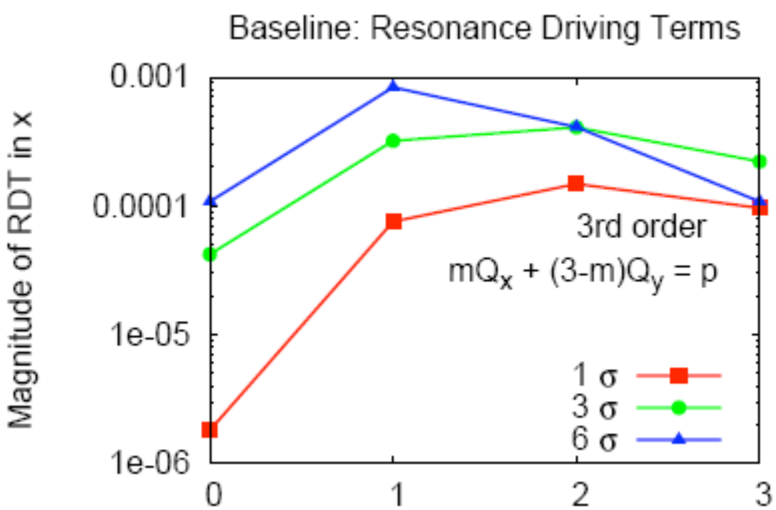
Beam-beam Tune Footprints

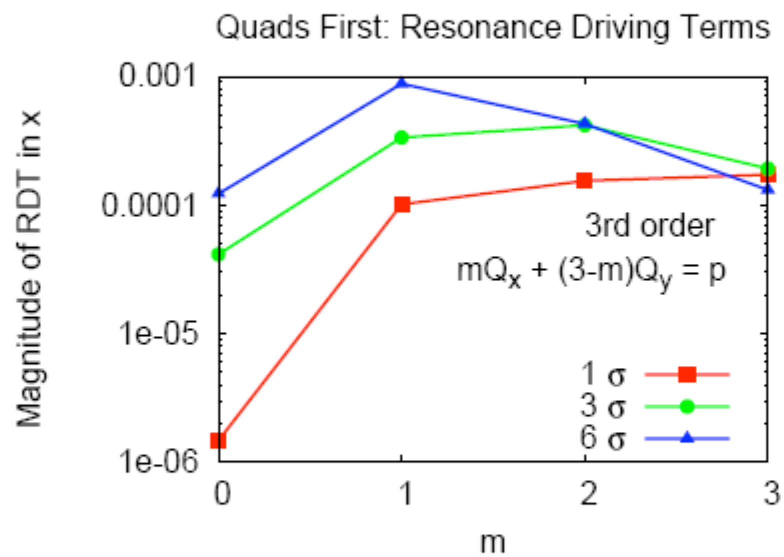


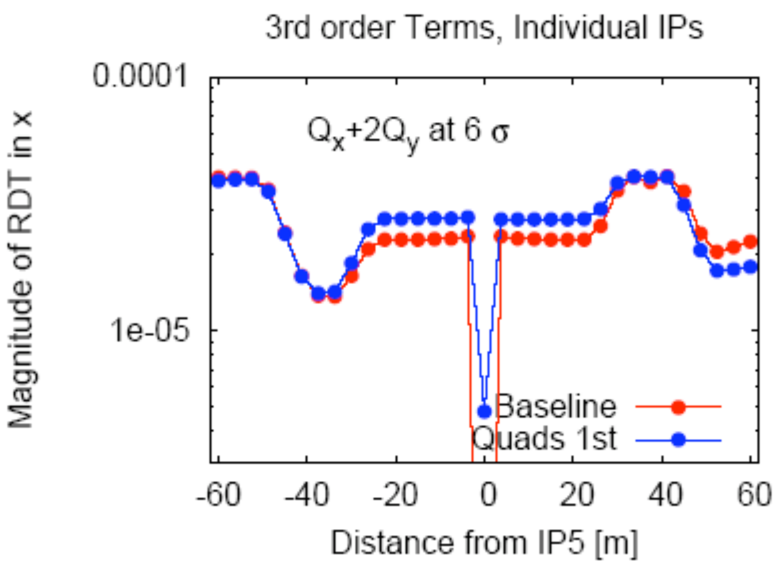


- Quads 1st: Tune footprint is nearly the same as in the baseline
- Dipoles 1st: Footprint is smaller at amplitudes > 2 σ

3^{rd} Order Beam-beam Interactions - Quads First

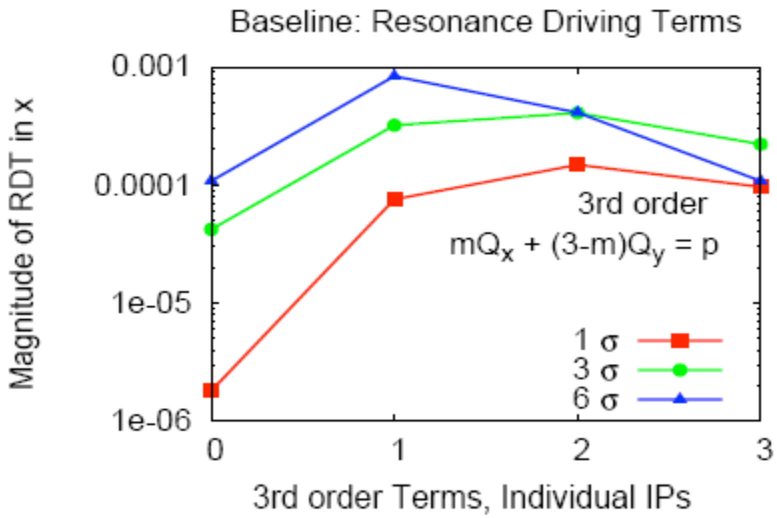


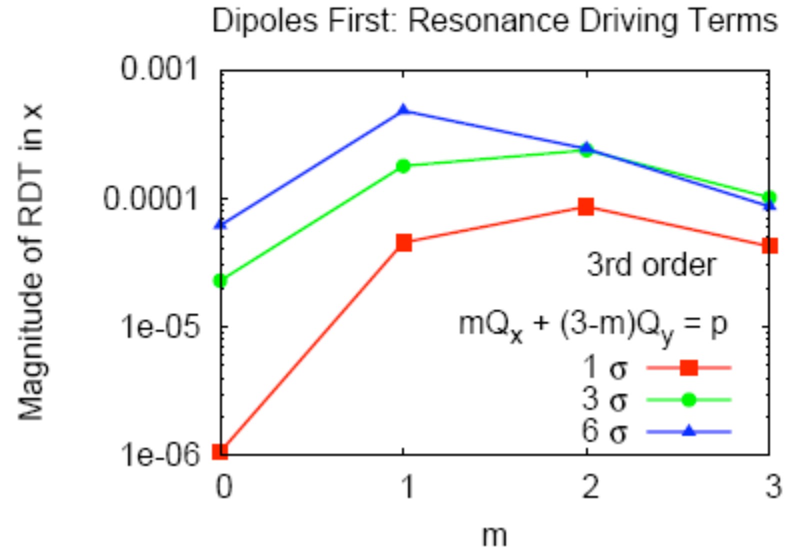


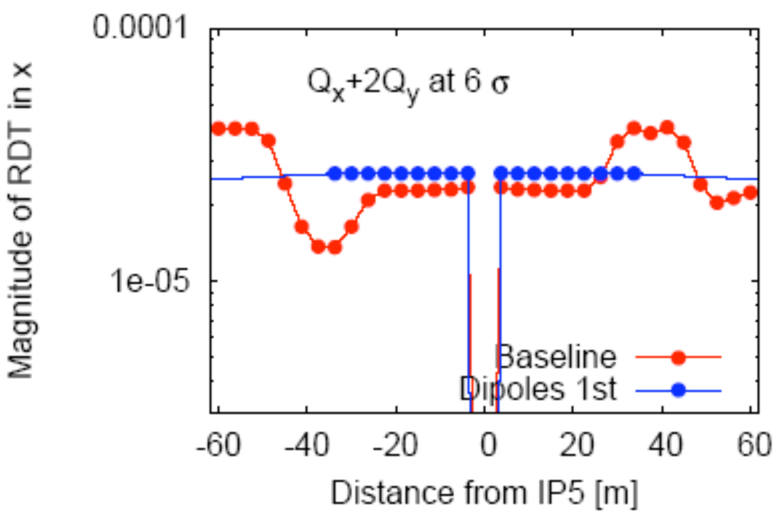


3rd order interaction strengths are comparable in the two optics, But slightly higher in the upgrade

3rd Order - All Beam-Beam Interactions (dipoles first)

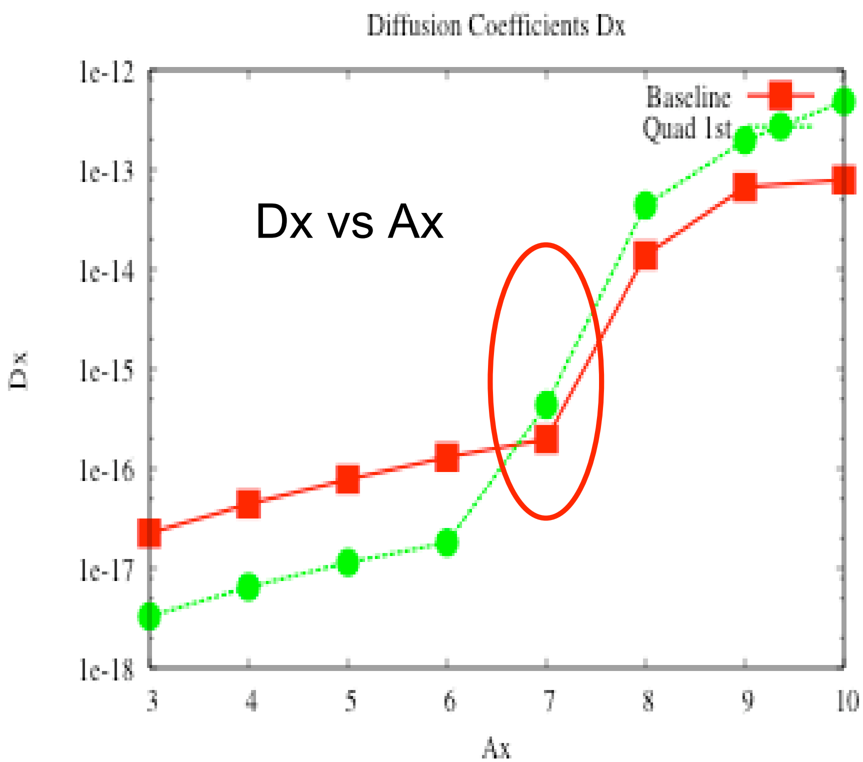


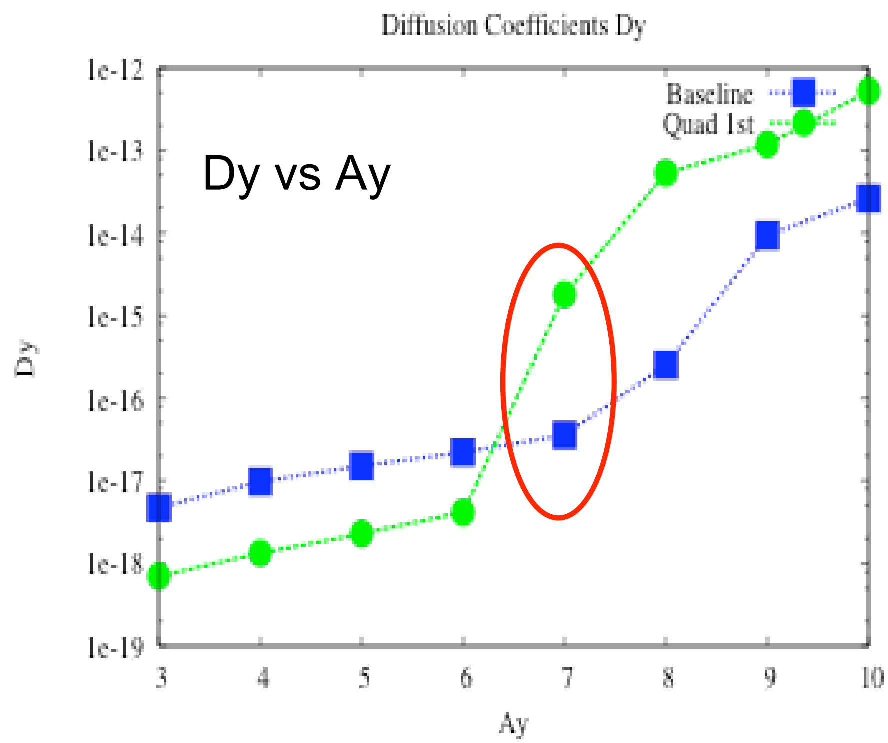




3rd order resonances with dipole 1st are about factor of 2 smaller

Diffusion coefficients - quads first

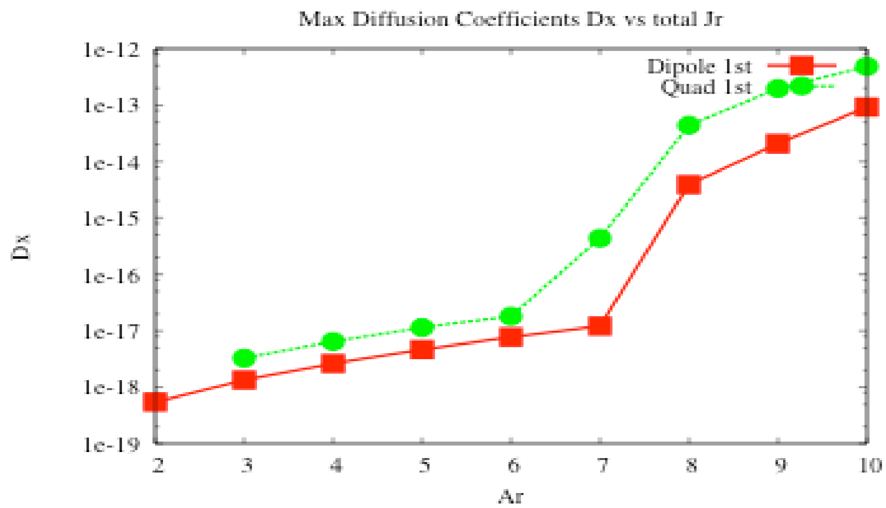


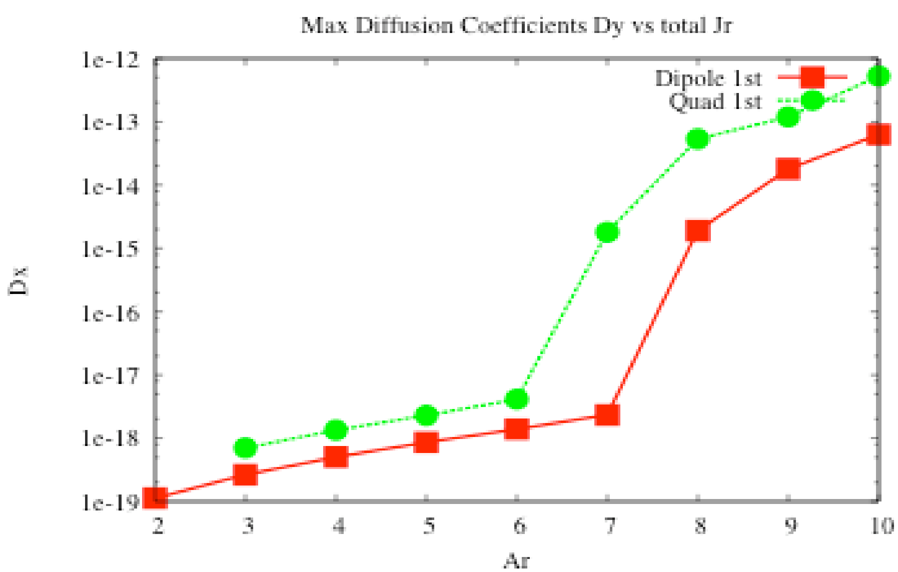


Diffusion for the upgrade quads first optics is stronger

Onset of jump in diffusion occurs about 1σ earlier at 7σ

Diffusion Coefficients - dipoles first





- Tracking with BBSIM - only the beam-beam nonlinearities
- In the dipole first optics, diffusion coefficients in both planes increase sharply at 8σ
- In the quad first optics, jump occurs at 7σ
- At amplitudes > 7σ, diffusion in quad first optics is at least 1 order of magnitude greater.

Energy Deposition (quadrupoles first)

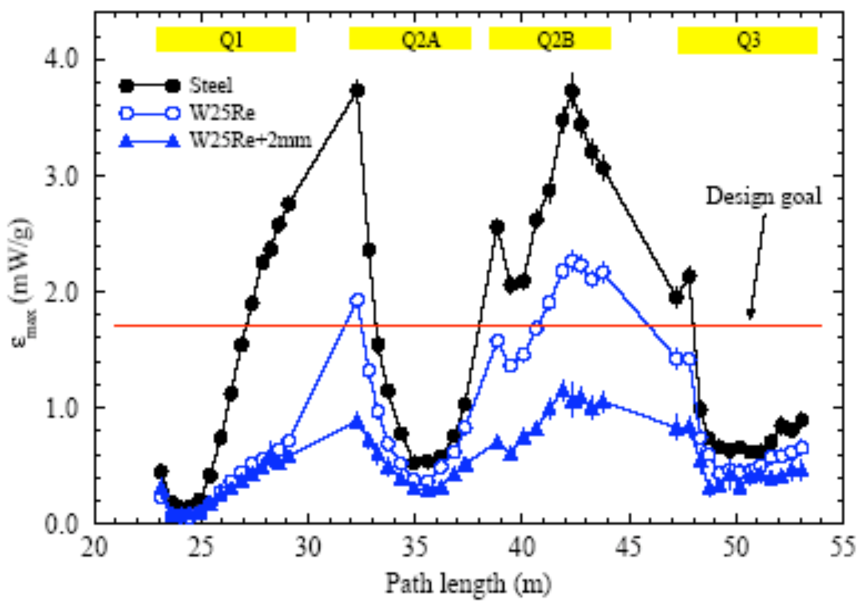
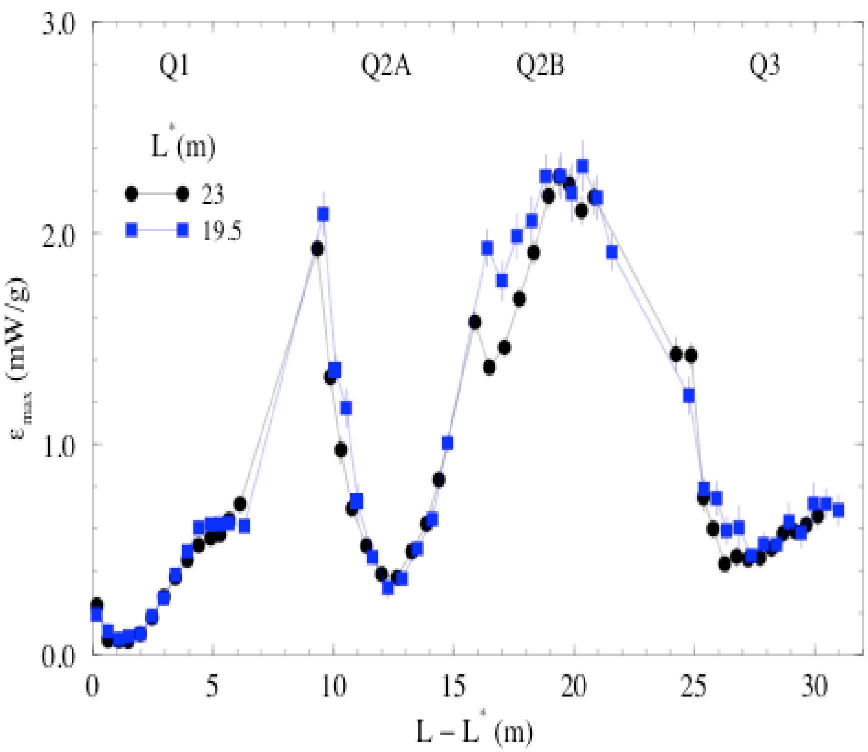


Figure 10: The peak power density in the inner coil of the 100-mm Nb_3Sn quadrupoles calculated for the baseline thickness of stainless steel, *W25 Re* liners, and for a *W25 Re* liner of increased thickness. *W25 Re* is used to replace both the steel liner and 1.5-mm steel cold bore adjacent to the liner (see Fig. 2).

N. Mokhov and I. Rakhno

Energy deposition simulations for the upgrade optics show that peak energy deposition in the IR quads can be kept below quench levels by suitable choice of beam-pipe material, thickness and liner

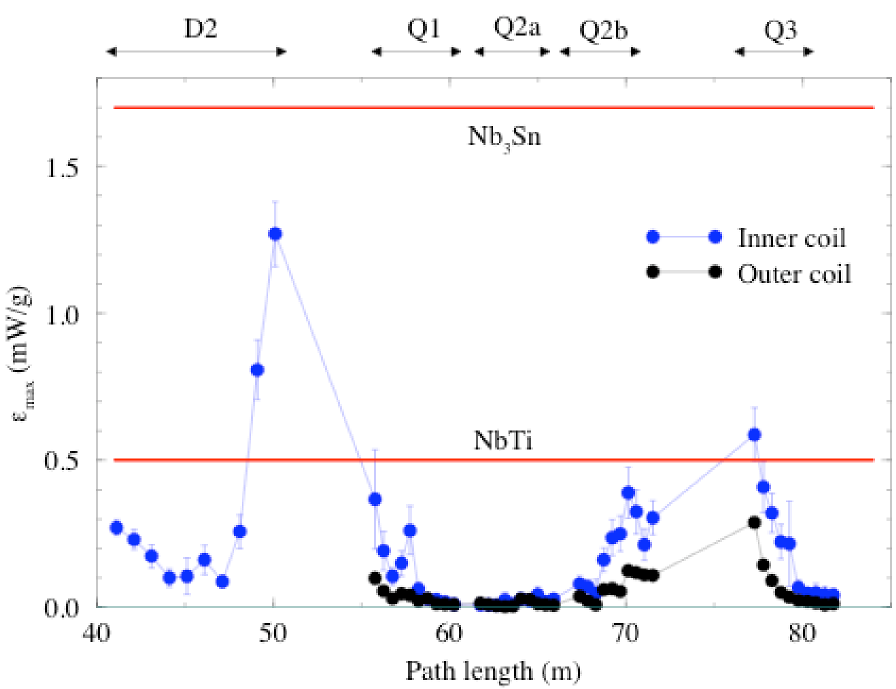
Energy deposition vs L* (quads first)



N. Mokhov and I. Rakhno

- Peak energy deposition and heat loads calculated for L*=19.5m. Results are close to values for L*-23m.
- L*=23m: Ltrip = 23.6m, and for L* = 19.5m, Ltrip = 25m, difference about 6%
- Calculations for other values of L* in progress.

Energy Deposition (dipoles first)



N. Mokhov, I. Rakhno

- Dipole first optics with triplet focusing
- D1 is an open mid-pane dipole, D2 is conventional cos θ dipole.
- Peak power deposition below quench limits for Nb3Sn
- Peak has moved from Q2b to D2
- **Heat load in the triplets lower than in quad first option**

Dipoles First: Doublets vs Triplets

LARP

- Pole tip fields and apertures are slightly larger with triplets

- Beam-beam Interactions

  - Head-on collisions with elliptical beams (doublet) seem to produce more emittance growth

  - Tune footprint due to all head-on and long-range interactions with elliptical beams is larger than with round beams.

  Expect the beam-beam effects to be worse with doublet optics

- Chromaticity

  - Symmetric optics in the inner quads significantly increases chromaticity with doublet optics

- Luminosity

  Doublet optics requires smaller crossing angles, **gain in luminosity**

Comparison: quads 1st vs dipoles 1st (triplets)

	Quads 1st	**Dipoles 1st**
Lowest β* at L* = 19.5m	0.22	0.23
Lumi gain at L*=19m vs L*=23 m	1.04 – 1.15	1.02 – 1.09
L* = 23m		
β^{Max} [m] at β* = 0.25m	9484	26092
Max aperture [mm]	101	107
Max pole tip field [T]	10.1	10.7
Q' of ring	-200, -194	-333, -340
Max 3rd order bb resonance	0.9×10^{-3}	0.5×10^{-3}
Max 10th order bb resonance	0.16×10^{-3}	0.3×10^{-5}
Beam-beam diffusion	Jump at 7σ	Jump at 8σ
Max Energy Deposition in quads [mW/g]	~ 1.0	~ 0.6

Options with Quads first and Dipoles First

Summary of Valencia Workshop

Quads First Optics

1) Baseline layout with larger aperture Nb3Sn quads, perhaps at reduced L*
   - Advantage: "More of the same", easier to commission (?)
   - Disadvantage: Gain in luminosity is limited w/out additional measures
2) D0 dipole inside the detector followed by Nb3Sn triplet
   - Advantage: Larger gain in luminosity, reduces the crossing angle
   - Disadvantage: Integration with detector, energy deposition (?)
3) Quad doublet ("Q0") NbTi magnets inside detector followed by triplet
   - Advantage: Reduces βmax, eases constraints on aperture, field errors
   - Disadvantage: Integration in detector, luminosity very sensitive to alignment

Dipole first optics:

- Advantages: weaker beam-beam effects, lower energy deposition in triplets
- Disadvantages :
  - Requires open midplane design for D1 - no effort on this at present
  - Much larger chromaticity
  - Greater length of absorbers (TAS, TASA, TAN)

Luminosity enhancements

- Wire compensation

This could be helpful with either the baseline quads first layout or even with Q0 magnets to reduce the crossing angle or increase in beam current - gain in luminosity

- Crab cavities for small crossing angles (< 1 mrad)

Same comment as above but could be used to recover the geometric loss of luminosity with either quad option 1) or 3).

- Electron lens compensation

Compensation of head-on interactions and reduce emittance growth, could be tested at RHIC

Next Steps for IR and Beam-beam

I. Quads first options - all three

- Energy deposition with magnets in detector
- L* dependence - luminosity, beam-beam effects, chromaticity
- Magnet parameters - aperture, gradients, field quality
- Nonlinear chromaticity correction (?)

To be coordinated with optics efforts at CERN (AB and AT depts)

II. **Beam-beam compensation schemes**

- **Wire compensation expts at RHIC, analysis for LHC**
- **Analysis of electron lens for head-on compensation**

III.

- Dipoles first: finish energy deposition studies
- Crab cavities with small crossing angle - optics design with “global” crab cavities